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Recommended Citation

Neilson, B. J., Hershner, C. H., & Greiner, M. K. (1995) Modeling cumulative impacts and the carrying capacity of small tidal creeks and inlets. Virginia Institute of Marine Science, William & Mary.
<https://doi.org/10.25773/cy7y-z029>

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Modeling Cumulative Impacts and the Carrying Capacity of Small Tidal Creeks and Inlets

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SEP 1 1995

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*This report was funded, in part by the Department of Environmental
Quality's Coastal Resources Management Program through Grant
#NA470Z0287-01 of the National Oceanic and Atmospheric Administration,
Office of Ocean and Coastal Resource Management, under the Coastal Zone
Management Act of 1972, as amended.*

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INTRODUCTION

Estimation of water quality impacts associated with use changes on land or water is primarily dependent on knowledge of what will be added to the water as a consequence of the change in use. Understanding of the mixing and transport of substances added to water bodies is reasonably advanced, with numerous mathematical models available to generate assessments of dilution and dispersion. The accuracy of model output is constrained, however, by the accuracy of the estimates of what is being added to the water (loadings). Frequently, loading of pollutants is unknown and extremely difficult to measure.

When pollutant loading occurs as a result of point source discharge, measurement of amounts added can be determined if concentrations and flow rates are known. While not a trivial problem, it is usually possible to mount an outfall sampling program sufficient to generate the required estimate. The problem is much more intractable when dealing with nonpoint source pollution. Addition of nutrients, sediments, biological and chemical oxygen demand, fecal coliforms and other substances to water bodies from surrounding lands is generally variable in both time and space. Estimating a time and space averaged loading is a difficult undertaking requiring extensive long term sampling of all the various delivery pathways. Few studies have undertaken the comprehensive sampling necessary to generate such numbers.

Even when estimates of pollutant loadings are developed, application of the estimates to

areas outside of the original sampling site entails an enormous number of assumptions about modes and rates of delivery, assumptions which are rarely documented or tested. As a consequence, prediction of water quality impacts, and particularly cumulative impacts, remains a speculative undertaking. Model output can be no better than the quality of the data used as input.

The purpose of this project was to identify pollutant loading values which might be used as input for a series of water quality models applied to small tidal creeks and inlets in Virginia's coastal plain. The intent was to identify values from literature sources which might be used in application of the models, absent better or more site specific information. Estimates of biological oxygen demand, chemical oxygen demand and fecal coliform loadings were of specific interest.

FINDINGS

Numerous studies have sought to determine pollutant loads associated with different land uses through intensive field work and long term sampling (*eg.* Clesceri et al., 1986; Beulac et al. 1982; Sonzogni, 1980). The majority of these works measure pollutant input through surface runoff following rainfall events. Runoff export coefficients are calculated as average annual pollutant loads per unit area. There are several limitations to broad application of these values. While studies have suggested that land use is the most important factor controlling pollutant loads in runoff waters (*eg.* Rast et al. 1983, Whipple et al. 1978), the net input of pollutants is understood to be a result of rainfall intensity and frequency, soil type, watershed slopes, and small scale patterns of land cover/use. Transport through groundwater pathways is also understood to be locally important and highly variable. Incorporation of all of these considerations in water quality models, while an objective of ongoing work, is not yet practical. Current models, and particularly those developed in the related work for this project, rely primarily on measures of land use and a generalized runoff coefficient.

Uttormark et al. (1974) concluded from a survey of literature that there is little

justification for the delineation of land useage beyond categories of urban, agriculture, forest and pasture. Thus, most studies report values for these classes of land uses. A survey of the literature indicates loading values can vary widely, generally over one to two order of magnitude for any single pollutant and land use type.

This report provides a summary of values for both runoff coefficients (TABLE 1) and storm water runoff load estimates (TABLE 2) for total suspended solids, biological oxygen demand, coliform levels, chemical oxygen demand, total nitrogen and total phosphorus.

SPECIAL NOTE FOR FECAL COLIFORMS

Estimation of fecal coliform loadings is particularly important in efforts to evaluate projects proposing marina construction. At the present time, the number of boat slips available in a marina is used as a predictor of probable pathogen concentrations in surrounding waters. The purpose of this determination is to set shellfish harvest controls, hopefully preventing the harvest and/or marketing of shellfish which might contain unacceptably high concentrations of pathogens. The assumption that slip number is an adequate predictor of pathogen concentrations is generally viewed as grossly oversimplified, but it has served as a practical solution absent more sophisticated methods of prediction.

One of the goals of this project was generation of mathematic models which might enhance the ability of managers to assess probable pathogen loading around marinas. The models basically estimate dispersion of fecal coliforms (used as an indicator of pathogen levels) based on circulation patterns. Model output is clearly dependent on the initial loading assumption. This number is extremely difficult to estimate with any accuracy.

In 1985, the United States Environmental Protection Agency developed a Coastal Marinas Assessment Handbook. The purpose of the handbook was to provide guidance in the design and

evaluation of marina projects. As part of that undertaking, the EPA contractor conducted an extensive review of available information in an effort to determine the fecal coliform loading attributable to each boat in a marina. The handbook referenced work done by Carstea et al. 1975 in identifying the assumptions necessary to develop an estimate. These assumptions include:

- average persons per boat is three;
- average per capita discharges of coliform bacteria and BOD are 2 billion and 75.6 g respectively;
- half of the people on board contribute fecal material in 24 hours;
- coliform bacteria populations do not increase;
- a boat in use spends one hour in the marina;
- 25 to 40 percent of boats present are in use and evenly distributed.

The difficulties associated with use of a number based on all these assumptions is self-evident.

The estimation of fecal coliform loading per boat in a marina is further complicated by the increased use of on-board marine sanitation devices. An even greater uncertainty derives from the potential influx of fecal coliforms from non-point sources. Schima et al. 1994 investigated the relationships between fecal coliform levels at 2,614 sampling stations and their landscape positions. They found a basic pattern of increasing fecal coliform bacteria densities with distance upstream in tidal creeks and inlets. They referred to this as a "land mass" effect, or simply the amount of land within a fixed radius of sample locations. Regression analysis of the MPN concentrations at sampling points along the Eastern Shore of Virginia indicated the following variables (in order of decreasing importance) were significant in explaining changes in the sampled MPN values:

- surface area of water in a 400 m radius around the sampling point
- season
- tide stage during sampling
- rainfall amounts in the 2 days prior to sampling
- surface area of urban land in a 400 m radius around the sampling point

- near shore groundwater hydraulic gradient
- salinity
- proximity to nearest shoreline
- near shore soil permeability
- near shore runoff events
- surface area of agricultural land in a 400 m radius around the sampling point
- near shore Darcy velocity
- water temperature

One conclusion to be drawn from all of this is that while fecal coliform inputs from nonpoint sources on land may be very important, they are also very variable and difficult to predict, even on the basis of land use.

TABLE 1

LOADING RATES BY LAND USE (kg/ha/yr)

LANDUSE		TSS	BOD	COLIFORM	SOURCE
residential		420	35	-	Wanielista, 1978
		11-487	-	-	Bannerman et al., 1984
		360-390	-	-	Marsalek, 1978
		620-2,300	-	-	Sonzogni, 1980
		-	30-50	-	Loehr, 1974
		-	-	25,621-	Ellis, 1986
		-	-	82,500(mpn/g)	
commercial		840	87	-	Wanielista, 1978
		957	-	-	Bannerman et al., 1984
		360	-	-	Maralek, 1978
		50-830	-	-	Sonzogni, 1980
		-	-	36,900(mpn/g)	Ellis, 1986
agriculture	mean	450	18	-	Wanielista, 1978
	range	180-4,200	4-31	-	
pasture	mean	343	11.5	-	Wanielista, 1978
	range	10-840	6-17	-	
forest	mean	85	5	-	Wanielista, 1978
	range	15-132	2-7	-	

TABLE 1 (continued)

LOADING RATES BY LANDUSE (kg/ha/yr)

LANDUSE		TN	TP	SOURCE
residential		5.0-7.3	-	Sonzogni, 1980
		9-11.2	1.6-3.4	Marsalek, 1978
		5.4-18.0	1.00-2.47	EPA, 1983
		6.6	1.8	Wanielista, 1978
		-	1.2-8.0	Whipple et al., 1978
commercial		1.9-11	-	Sonzogni, 1980
		11.2	3.4	Marsalek, 1978
		16.3	2.22	EPA, 1983
		14.5	2.7	Wanielista, 1978
pasture	mean	6.2	0.5	Wanielista, 1978
	range	2.0-12.0	0.1-2.1	
		4.94	0.74	Beulac & Reckhow, 1982
		-	0.34-0.56	Mackiernan, 1985
agriculture		8.89	2.22	Beulac & Reckhow, 1982
	mean	26.0	1.05	Wanielista, 1978
	range	15.0-37.0	0.18-1.62	
		-	1.68-5.6	Mackiernan, 1985
		-	0.06-2.9	Loehr, 1974

TABLE 1 (continued)

LOADING RATES BY LANDUSE (kg/ha/yr)

LANDUSE		TN	TP	SOURCE
forest	mean	3.0	0.10	Wanielista, 1978
	range	2.0-5.1	0.01-0.86	
		2.47	0.25	Beulac & Reckhow, 1982
		-	0.06-0.11	Mackiernan, 1985
		-	0.03-0.9	Loehr, 1974

TABLE 2

STORM WATER RUNOFF ESTIMATES (mg/l)

POLLUTANT			SOURCE
TSS		141-224	EPA, 1983
		1,401-2,909	Wanielista, 1978
	urban	227	Carstea et al., 1975
	Durham, NC	mean 1,440	Colston, 1974
		range 194-8,620	
	agricultural	90-5,000	Dornbush et al., 1974
	watershed	180-6,000	
	cultivated	1,021	
	pasture	38	
BOD	urban area	12-160	Loehr, 1974
		17	Carstea et al., 1975
	Cincinnati, OH	mean 19	Weibel et al., 1964
		range 2-84	
	agricultural	7	Loehr, 1974
	watershed	5-30	Dornbush et al., 1974
		3-15	
COLIFORM		1,000-	
		21,000 MPN/100ml	EPA, 1983
		> 2,000 MPN/100ml	Olivieri et al., 1977
	Washington, DC	76,100	Wanielista, 1978
	Durham, NC	mean 23,000	Colston, 1974
		range 100-200,000	

TABLE 2 (continued)

STORM WATER RUNOFF ESTIMATES (mg/l)

POLLUTANT				SOURCE
COD	Durham, NC	mean	170	Colston, 1974
		range	20-1042	
	Cincinnati, OH	mean	99	Weibel et al., 1964
		range	20-610	
	agricultural watershed		50-360	Dornbush et al., 1974
	pasture		70-780	
TN			49	
			5.6-7.1	EPA, 1983
	urban area	mean	3.1	Weibel et al., 1966
		range	0.3-75	
			3.1	Carstea et al., 1975
	forested		0.3-1.8	Loehr, 1974
	agriculture		9.0	Loehr, 1974
TP			0.4-0.5	EPA, 1983
	agriculture		0.04-2.4	Dornbush et al., 1974
	forested		0.01-0.11	Loehr, 1974
	agriculture		0.02-1.7	Loehr, 1974
	urban area		0.2-1.1	Loehr, 1974
			1.1	Carstea et al., 1975

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